FINAL REPORT
IHR-513
CRACK CONTROL
OF
POZZOLANIC BASES

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16. Abstract

Illinois Department of Transportation policies permit four types of stabilized base courses for flexible pavements: bituminous, cement, cement fly ash, and lime fly ash aggregate mixtures (BAM, CAM, CFAM, and LFAM, respectively). Collectively, CFAM and LFAM base courses are known as pozzolanic aggregate mixtures (PAM). At one time, LFAM base courses were popular in the metropolitan areas due to their low cost. As a result, several projects in these areas were built using LFAM as a base course material.

The LFAM base course gains its strength through chemical reactions very similar to those characterizing Portland cement concrete. During this process, moisture is depleted, the mixture shrinks, and cracks occur. These cracks inevitably reflect through the bituminous surface.

To combat this problem, Illinois borrowed a technique used by Portland cement concrete pavers. Joints were cut in the newly placed LFAM base course to control the location of the cracks and, hence, the reflective cracks. Several joint designs and joint spacings were evaluated. This paper describes the designs, summarizes their costs, and evaluates their effectiveness.

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I. INTRODUCTION

Current Illinois Department of Transportation policies permit four types of stabilized base courses for flexible pavement. These are:

BAM - Bituminous Aggregate Mixture
CAM - Cement Aggregate Mixture
CFAM - Cement Fly Ash Aggregate Mixture
LFAM - Lime Fly Ash Aggregate Mixture

Collectively, CFAM and LFAM base courses are known as pozzolanic aggregate mixtures (PAM). At one time, LFAM bases were popular with some contractors in the Chicago and East St. Louis areas due to their low cost. As a result, several projects in these areas were built using LFAM as a base course material.

The LFAM base course gains its strength through chemical reactions very similar to those characterizing Portland cement concrete. During this process, moisture is depleted, the mixture shrinks, curls, and cracks occur. These cracks inevitably reflect through the bituminous surface.

The appearance of wandering reflection cracks in the bituminous surface detracts from the appearance of the new roadway and disturbs the traveling public. Although the cracking initially is a cosmetic problem, the chances of long-term durability problems also are increased. The cracks allow water, often containing deicing salts, to enter the base. The salt water, combined with freeze-thaw cycles, may lead to localized deterioration and a decrease in rideability.

These shrinkage cracks cannot be avoided. However, the concrete industry controls the location and shape of the cracks by sawing joints at periodic intervals in the freshly placed concrete. If the same approach would work for LFAM base courses, saw cuts in freshly placed LFAM would induce straight cracks, resulting in straight reflective cracks in the asphalt surface. These regularly occurring "joints" in the surface course would be more acceptable to the public and could be "waterproofed" by any of several techniques, possibly improving long-term performance.

The spacing of saw cuts in the LFAM base course was considered critical. If the cuts were too far apart, cracking might occur between the "joints". If the spacing was placed closer than necessary, the cost could become prohibitive. In 1982 the Department decided to construct an experimental section to determine the feasibility of crack control for LFAM bases.

II. PAVEMENT EVALUATION SECTIONS

Project Number 1 - Ogden Avenue

In 1982 an experimental section, designed to evaluate the effectiveness of this crack control method and determine the proper crack spacing, was incorporated into a project already under contract. The project selected was the reconstruction of Ogden Avenue (U.S. Route 34) in Lisle, Illinois, located southwest of Chicago.

This section of Ogden Avenue, located one mile east of Illinois Route 53, is a two-directional, five-lane facility. Due to the numerous businesses along the route, the center lane is dedicated to left-turn movements. Average daily traffic is 20,000 vehicles, with less than one percent commercial truck traffic.

The typical cross section for the reconstruction called for 4 inches of granular subbase, 10 inches of LFAM base, 3 inches of bituminous binder and 1 1/2 inches of bituminous surface. Curb and gutter were constructed along the entire project with numerous entrances provided for businesses.

The 1,005-foot experimental feature consisted of three separate designs. In each case, construction of the subbase and base courses was governed by the existing contract specifications. Only after the LFAM base course had been compacted and sealed for curing did the construction procedures vary. The three designs are listed below:

<u>Design A</u>: Joints were cut in the LFAM base course to a depth of 3 1/2 inches. Binder and surface were placed directly over the LFAM base course.

Design B: Joints were cut to a depth of 3 1/2 inches in the LFAM base course. Binder and surface were placed. Joints were then cut three inches deep and approximately 3/8 inch wide into the asphalt directly over the joints in the LFAM base course. These surface joints were then sealed with hot-poured rubberized asphalt.

Design C: Joints were cut to a depth of 3 1/2 inches in the LFAM base course. A 24-inch wide geotextile strip was placed over the joint using an AC-10 to bond it in place. The binder and surface were then placed.

The joint designs used on Ogden Avenue are shown in Figure 1. Each of the three designs incorporated joint spacings of 15, 25, and 40 feet as shown in Figure 2.

In order to accurately locate the joints, saw cuts were made in the newly formed curb and gutter on both sides of the pavement. By stringlining from curb joint to curb joint, the surface joints were aligned directly over the base joints. A 1,000-foot control section, consisting of normal construction and no joints, was selected adjacent to the experimental section for comparison purposes.

Project Number 2 - Vollmer Road

A second experimental section was constructed in 1985 to study additional joint designs and spacings. This project was located on Vollmer Road, between Dixie Highway and Halsted Street (Illinois Route 1), in Chicago Heights, Illinois. As with the Ogden Avenue project, the experimental section was incorporated after the project was under contract.

This portion of Vollmer Road is a two-directional, variable-lane facility. The project is located in a residential area. Average daily traffic was approximately 9,200 in 1982. The typical cross section consisted of 4 inches of granular subbase, 8 inches of LFAM base, and 3 inches of bituminous binder and surface.

The one mile long Vollmer Road section was similar to Ogden Avenue in that both joint spacing and joint design were investigated. On Vollmer Road, however, the emphasis was on joint design. The primary joint spacing used was 40 feet. In one of the three joint design sections, a small number of joints were spaced at 60 and 80 feet. Joint designs were as follows:

Design D: The LFAM base and bituminous binder courses were placed. Joints 1/4 inch wide were cut through the binder and 2.6 inches into the LFAM base course. After cleaning the joint, a backer rod was placed and the joint sealed with a hot-pour rubberized asphalt sealant. The bituminous surface was placed and a saw cut made directly over the previously cut joint. The surface joint was then cleaned, a backer rod placed, and the joint sealed with a hot-pour rubberized asphalt sealant.

Design E: After the initial set, joints 1/4 inch wide were cut in the freshly laid LFAM to a depth of 2.6 inches, after which the joints were cleaned, a backer rod placed, and the joints sealed with a hot-poured rubberized asphalt sealant. The bituminous binder and surface courses were placed. Joints 1/4 inch wide and 2.6 inches deep were then cut into the asphalt directly over the joints in the LFAM base course. These joints were cleaned, a backer rod placed, and the joints sealed with a hot-poured rubberized asphalt sealant.

Design F: The LFAM base course and the two bituminous courses were placed. Then a single 1/4 inch wide saw cut was made through the bituminous mat and 2.6 inches into the LFAM base. The joint was cleaned, a backer rod was placed, and the joint sealed with a hot-poured rubberized asphalt sealant.

The joint designs used on Vollmer Road are shown in Figure 3. Figure 4 shows the joint spacing layout for the Vollmer Road experimental section.

III. CONSTRUCTION

The specific dates and the seauence of construction for the experimental sections on Ogden Avenue are shown in Table 1. Pertinent details of the construction operation are summarized below.

The westbound curb and gutter were formed, placed and then sawed at intervals to match the base joints in the experimental section. In the control section, the curb was sawed every 40 feet. The eastbound curb and gutter were slip formed. Joints were sawed to match the location in the westbound curb. Although the sawing was accomplished within 24 hours of placement, an occasional shrinkage crack developed very close to the saw cut, as shown in Figure 5.

The LFAM was placed full-depth with a Jersey spreader box on the front of a bulldozer. The LFAM was then compacted with a vibratory roller, bladed to final grade with a motorgrader, and compacted once more with the vibratory roller. The lack of automatic grade control caused considerable deviation from the design grade. High areas were removed by trimming and the low areas were filled with extra bituminous binder to reach the correct elevation.

Figure 6 shows a small concrete saw being used to cut 3 1/2-inch deep joints in the LFAM base on the day following placement. The prime coat used to seal the LFAM did not seem to affect the cutting operation.

Figure 7 shows the freshly cut joints being cleaned with an air compressor. It was observed that if more than an hour elapsed between the cutting and cleaning operation, the LFAM cuttings had "set up" and it was difficult to clean the joints.

The contractor selected Amopave CEF 4599 as the geotextile to be used for crack control in Design C. After cutting and cleaning the joint, a distributor applied AC-10 to the sealed LFAM base for a distance of 2 1/2 feet either side of the joints, as shown in Figure 8. The 24-inch wide Amopave fabric was centered over the joints and broomed smooth in accordance with the manufacturer's instructions. The application rate for the AC-10 was controlled by the distributor operator's judgement and may have been heavier than desirable.

After the surface had been placed on all five lanes, a joint was cut through the surface for the 13 joints of Design B, as shown in Figure 9. The depth of cut varied from 3 to 3 1/2 inches. The joint width was kept constant at 3/8 inch. By string lining from curb joint to curb joint, the surface cuts were aligned directly over the base joints. The joints in the surface were then sealed with a rubber asphalt joint sealer that met the ASTM D 3405 specification.

Construction of the Vollmer Road experimental section followed similar procedures. The joints were 1/4 inch wide and contained a 3/8 inch backer rod. All of the joints on this project were sealed with rubber asphalt joint sealer meeting ASTM D 3405 specifications. Construction proceeded smoothly and no significant problems were encountered.

IV. PERFORMANCE OF EXPERIMENTAL FEATURES

Crack Surveys

The experimental and control sections of Ogden Avenue were surveyed annually between 1983 and 1986. These sections were removed in 1988 during construction of an interchange, thus preventing further study. Vollmer Road was surveyed in 1986 and 1987. A summary of the observations is given below:

Ogden Avenue Experimental Sections: Four years after construction, every joint had reflected through the surface with 1-2 minor transverse cracks present between some of the joints in Designs A and C. The number of intermediate transverse cracks found in each joint design and spacing are shown in Table 2. The 15-foot joint spacings in Design A and the 15-foot and 25-foot joint spacings in Design C appear to have performed somewhat better than the longer joint spacings within the individual designs since these cracks had not yet reflected the full width of the pavement after four years. Based on the greater number of intermediate cracks found in the 40-foot joint spacing and the slower rate of reflective cracking in the shorter joint spacings, it seems apparent that the 15-foot to 25-foot joint spacings are better suited to controlling the rate and severity of reflective cracking.

The appearance of Design B is far superior to Designs A and C. Design A controlled the location of the cracks to a large degree, but the cracks appeared ragged and difficult to seal. The surface joints in Design B look very much like Portland cement concrete joints. However, due to an improper joint design, the sealant has not bonded well to the joint. The reservoir shape factor of Design B was 8:1 (3 inches deep by 3/8 inch wide). A reservoir with a shape factor closer to 1:1 could be expected to hold a bond better. Design C appears to be the poorest of the three designs. The reflected surface cracks are ragged, similar to those in Design A, but seem to wander to a greater degree.

Ogden Avenue Control Section: The reflective cracks in the control section without joints have occurred at random intervals. While most of the cracks are perpendicular to the curb line, they rarely extend across the 55-foot pavement at one location. Instead, a series of shorter cracks, often offset by several feet, span the pavement. The cracks are ragged in appearance, very similar to those of Designs A and C. Figure 10 is a plan view of the crack locations in the control section after four years in service.

Vollmer Avenue Experimental Sections: The experimental sections were surveyed in 1986 and 1987 in conjunction with the deflection testing. Two years after construction, no intermediate transverse cracks were visible between the sawed joints. This project contained no control section that featured normal construction without controlled joints.

Deflection Testing

Deflection testing was performed every spring on both projects with either a Road Rater or a Dynatest 8002 Falling Weight Deflectometer (FWD). Road Rater deflections were measured using an 8,000-pound peak-to-peak load applied at 15 Hz. The FWD deflections were normalized to a 9,000-pound standard load. Deflections were measured on the approach and leave sides of each joint in all the experimental sections, and on the approach and leave sides of each crack in the Ogden Avenue control section. A summary of the average deflections and the average load transfer efficiencies for the six joint designs is presented in Table 3. Table 4 shows the average deflections and the average load transfer efficiencies for the different joint spacings on Ogden Avenue. The load transfer efficiency of a crack or joint is the ratio of the deflection of the unloaded side to the deflection of the loaded side.

Ogden Avenue

A look at the data in Table 3 shows little variation in the deflections between Joints A, B, and C. All of the deflections are considered low to average, indicating good base support at all locations. Initially, Design B had the highest deflection. This may have been attributable to the absence of some slab action since its surface was severed. As the cracks in Design A began to open up however, their deflections increased. The load transfer efficiencies show little variation between designs, although the average overall is higher for Design B.

Table 4 shows little variability between deflections or load transfer efficiencies for the different joint spacings. On the whole, the deflections tend to be lower for the 15-foot and 25-foot joint spacings. These findings support the results of the crack surveys.

Vollmer Road

The difference in deflections on Ogden Avenue and Vollmer Road shown in Table 3 can be attributed to the difference in pavement cross sections. Vollmer Road was a thinner section, with 3 inches of bituminous concrete over 8 inches of LFAM base, compared to Ogden Avenue's 4 1/2 inches of bituminous concrete over 10 inches of LFAM base. This accounts for the higher deflections found on Vollmer Road.

A comparison of Designs D, E, and F shows that Design F produces lower deflections and higher load transfer efficiencies. This could be caused by a localized area of additional base course thickness. These results are somewhat suspect because Design F delays cutting the LFAM base until after the bituminous concrete binder and surface courses have been placed. By the time these binder and surface courses have been placed, shrinkage cracks may have already developed in the LFAM base, nullifying the effect of the saw cut. Two years after construction, no intermediate transverse cracks had developed in any of the experimental sections. It is difficult to assess the optimum joint spacing since there was no control section, consisting of normal construction without controlled joints, or any replication of the longer spacings. The longer joint spacings, i.e., 40-foot or possibly greater, seem to perform satisfactorily when the surface has been sawed and sealed as in Designs B, D, E, and F. After limited service, these longer spacings show no intermediate cracking. However, after four years in service, the 40-foot sealed joints on Ogden Avenue did show signs of opening up. The sealant began pulling away from the walls of the joint, as shown in Figure 11. The sealant in the shorter joint spacings remained firmly adhered to the sides. As the reliability of the costs of the various designs is questionable, cost-effectiveness cannot be used to determine the optimum joint design or spacing.

Coring

Cores were taken from the Ogden Avenue project in June of 1987. Two or more cores were taken from each joint design and spacing with the exception of the 40-foot spacing in Design B, where only one core was taken. Cores were also taken at naturally occurring cracks in the control section and at center locations between joints in the experimental sections. The cores were taken to determine the quality of the LFAM base course material at the joints and cracks.

In general, the cores taken at naturally occurring cracks in the control section were in poor condition, as evidenced in

Figure 12. The bituminous concrete shows ragged cracks and the LFAM base course, where recoverable, had begun to disintegrate. Each core hole was also inspected after the coring was complete. In each case the hole appeared to contain sound material with the core hole walls being smooth except for the bottom 1 inch of the hole. In contrast, the cores in Figure 13 were taken from the center of "slabs", between joints and cracks, and show fairly sound and well compacted base material. The crack in the base course of the core on the right appears to have been caused by the roller during base course compaction. The surface of the base of this core is very uneven, and excess rolling to achieve compaction may have initiated the crack.

Figure 14 shows a matrix of the recovered cores grouped by joint designs and spacings. A comparison of the cores shows that Design B was the most successful at protecting the bituminous surface course by controlling the quality of cracking. The sealed surface joints do not detract from the pavement's appearance. The sealed joints also retarded the ravelling process as shown in Figures 15 and 16. The reflective cracks appearing above the base joints in Designs A and C are just that--cracks. The location has been controlled but the ragged appearance of the reflective cracks is not aesthetically pleasing.

In terms of protecting the LFAM base course, Design C appears to have been the most successful. The ragged surface cracks of Design A and the uncontrolled cracks in the control section allow water and deicing salts to penetrate to the LFAM base. This severe freeze-thaw environment results in disintegration of the base as evidenced by a less than complete core recovery. While the surface cracks in Design C do allow some water and deicing salts to penetrate, the geotextile fabric protects the LFAM base course to some degree.

A limited amount of strength testing was done on the cores and the results are listed in Table 5. Test results of cores taken from the center of "slabs", between joints and cracks, show the difficulties in obtaining compaction when the base course is placed in a single lift as the strength decreases with depth. Compressive strength results were converted to split tensile values for a core from the center of a "slab" and a core from Design C with a 40-foot joint spacing. The results show that the strength of the base course at a Design C joint protected by a geotextile is similar to the strength of the base course between joints and cracks.

Removal of Ogden Avenue Experimental Sections

In the spring of 1988, the Ogden Avenue experimental and control sections were removed during the construction of an interchange with the new North-South Toll Road. A longitudinal saw cut was made between the westbound lanes and the turn lane. The turn lane and eastbound lanes were then removed. This gave a unique opportunity to view the LFAM base course and the different joint designs.

It was found that all joints allowed moisture and salts to enter the pavement. At the edge of the moist crack, white deicing salts had crystallized. Unfortunately, this was typical of all joints viewed. A visual survey showed that Joint Design A had slightly more salt accumulated than Designs B, C, and the control section. Overall the base appeared sound in the joint and crack areas regardless of joint design.

Another observation made was that the bituminous binder exhibited little or no bonding to the LFAM base near cracks and joints. The bituminous curing coat placed on the LFAM base course was intact, but there was a slight amount of dust over the seal. This was also observed on some of the cores that were taken. Cores taken at Joint Designs A and B were not recovered with the base attached. Cores which were recovered from Joint Design C and the center of the slabs exhibited good bond.

The lack of bonding may have been due to the joint cutting operation through the LFAM base. The saw cuttings may have produced enough fines to cover the bituminous curing coat at the joints which made it ineffective as a tack coat.

V. COST OF DESIGN ALTERNATIVES

Since both projects were already under contract, the costs for incorporating the experimental section reflect negotiated rates. These costs are believed to be higher than if a competitive bidding situation had existed.

Ogden Avenue

- Sawing joints in the LFAM base - $0.91 per lineal foot (Joint Designs A, B, C)
- Geotextile application - $1.65 per lineal foot (Joint Design C)
- Sawing and sealing surface joints - $5.31 per lineal foot (Joint Design B)

Vollmer Road

- Joint designs D, E, and F each cost $2.00 per lineal foot

These prices can be converted into cost per square yard by dividing the cost of each joint treatment by the number of square yards between the joints. For Design A, each joint cost $50.05. For a 15-foot joint spacing, the area between joints was 91.67 square yards. Thus, the cost per square yard of pavement could be expressed as:

$$\frac{\$50.05}{91.67\ \text{yd.}^2} = \$0.55/\text{yd.}^2$$

Table 6 contains the costs on a square yard basis for each joint design and joint spacing.

Based upon actual bid prices of 4-inch granular subbase, 10-inch LFAM base, prime coat used for curing, 3-inch binder and 1 1/2-inch surface, the total cost of the Ogden Avenue pavement section was $13.36/yd.^{2}. Similar calculations yield a cost of $13.57/yd.^{2} for the pavement section on Vollmer Road. Dividing the costs of crack control, as shown in Table 6, by the total cost of the pavement produces a "percent increase of cost" for crack control. Table 7 contains these values.

The cost of the new pavement section for the Ogden Avenue reconstruction project was approximately 1/3 of the total project cost. Old pavement removal, drainage correction, and traffic control consumed 2/3 of the project dollars. The cost of the new pavement section for the Vollmer Road reconstruction project totalled approximately 1/4 of the total project cost. Table 8 presents the percentage increase in terms of total contract price for the various joint designs and spacings.

VI. CONCLUSIONS

Using procedures common to the concrete industry, cracking can be controlled in LFAM bases. By sawing joints in the freshly placed LFAM, straight reflective cracks can be introduced in the bituminous surface. To provide a crack control design which is aesthetically acceptable to the traveling public and which will reduce the intrusion of water and deicing salts, a sawed and sealed surface is required.

Deflection testing indicates there is little difference in performance between the three joint designs tested on Ogden Avenue. As seen during the removal of the Ogden Avenue experimental section, there seems to be little the designer can do to keep out deicing salts. Water carrying deicing salts can infiltrate at the joints, at the edge of the pavement, and perhaps even percolate through an open bituminous surface, thereby adversely affecting the performance of the LFAM base. From a visual review of the Ogden Avenue cores, however, it would appear that Design C, using a geotextile, is protecting the LFAM base course better than the other joint designs.

Likewise, Designs B, D, E, and F, using a sawed and sealed surface, seem to protect the bituminous surface better. These sawed and sealed joints did not ravel as the naturally occurring cracks did. From the standpoint of protecting both the LFAM base and the bituminous surface, a design incorporating a geotextile fabric and a sawed and sealed surface would appear to be the ideal joint design. Such a design was not tested however, and would likely be quite expensive.

The lack of mid-panel cracks on Vollmer Road would seem to suggest that joint spacings of up to 80 feet are practical. The Ogden Avenue data indicates that 40-foot panels are more prone to cracking, with the 25-foot panels giving very good performance. Differences in cracking may be due to traffic, cross section, or construction conditions over which the designer has little control. A reliable and cost-effective joint spacing would seem to be in the 25 to 30 feet range.

VII. RECOMMENDATIONS

- A joint design featuring a sawed and sealed surface, similar to Designs B, D, E, or F, should be used.
- A formed joint sealant reservoir, with consideration given to proper shape factors, is necessary.
- Joint spacing should not be greater than 30 feet.
- Additional brooming or a bituminous tack coat may be required on the LFAM base if a large amount of fines are present after joint cutting.
- If Designs D or F are used, special attention must be given to the time span between LFAM base construction and saw cutting the joints. The allowable time span may vary greatly depending upon the fly ash source and the time of year. If it is known that a mix will gain strength quickly due to high temperatures or fast-setting materials, then it may be desirable to require that the LFAM base be sawed as soon as possible after placement. More research is needed in this area. While CFAM bases were not evaluated in this study, their performance is expected to be similar to that of LFAM bases.

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The contents of this paper reflects the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation nor the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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TABLE 1

Construction Sequence for Ogden Avenue, 1982

DATE	OPERATION
Late June	Removed three lanes (two westbound lanes plus the turning lane); routed traffic onto the two remaining lanes.
July 21-28	Poured concrete curb and gutter for westbound lanes and saw cut the curb to match the experimental design (15, 25, and 40 feet).
August 10	4" granular subbase placed.
August 12	LFAM base placed and sealed.
August 13	Saw cut LFAM base for all three designs and placed fabric over joints for Design C.
August 16-18	Both binder lifts placed.
Early September	Traffic routed onto new binder and remaining two lanes (eastbound) removed.
September 20-21	Poured concrete curb and gutter for eastbound lanes and saw cut to match westbound curb.
September 23	4" granular subbase placed.
September 24	LFAM base placed and sealed.
September 25-26	LFAM base saw cut for all three designs and fabric placed for Design C.
September 28-29	Both binder lifts placed on eastbound lanes.
October 18-19	Surface placed on eastbound lanes.
October 27-28	Surface placed on westbound and turning lanes.
November 3-4	Saw cut surface in Design B.
November 8	Sealed joints in surface of Design B.

TABLE 2

Intermediate Transverse Cracking as a Function

of Joint Spacing on Ogden Avenue

JOINT DESIGN	NUMBER OF INTERMEDIATE TRANSVERSE CRACKS		
	15' SPACING	25' SPACING	40' SPACING
A	0	0	8
B	0	0	0
C	1	1	3

TABLE 3

Average Deflections and Load Transfer Efficiencies
as a Function of Joint Design

OGDEN AVENUE

EQUIPMENT	TEST DATE	AVERAGE DEFLECTION, MILS JOINT A	JOINT B	JOINT C	CONTROL
*ROAD RATER	7/25/84	5.03	5.33	4.85	6.23
*ROAD RATER	6/4/85	4.72	5.21	4.45	6.16
**FWD	9/9/86	8.13	7.42	6.01	6.98
**FWD	5/7/87	6.63	6.31	5.87	7.56

EQUIPMENT	TEST DATE	AVERAGE LOAD TRANSFER EFFICIENCY, % JOINT A	JOINT B	JOINT C	CONTROL
*ROAD RATER	7/25/84	74.9	82.7	78.4	77.2
*ROAD RATER	6/4/85	80.8	84.6	78.2	81.6
**FWD	9/9/86	72.0	72.0	74.2	73.3
**FWD	5/7/87	71.5	71.1	69.2	72.2

VOLLMER ROAD

EQUIPMENT	TEST DATE	AVERAGE DEFLECTION, MILS JOINT D	JOINT E	JOINT F	CONTROL
**FWD	9/8/86	14.37	16.42	10.55	N/A
**FWD	4/8/87	17.13	19.74	11.91	N/A

EQUIPMENT	TEST DATE	AVERAGE LOAD TRANSFER EFFICIENCY, % JOINT D	JOINT E	JOINT F	CONTROL
**FWD	9/8/86	73.8	67.0	72.2	N/A
**FWD	4/8/87	61.8	66.0	74.7	N/A

*ROAD RATER TESTED USING AN 8,000-POUND PEAK-TO-PEAK LOAD APPLIED AT 15 Hz.

**FWD DATA NORMALIZED TO A 9,000-POUND LOAD

TABLE 4

Average Deflections and Load Transfer Efficiencies
as a Function of Joint Spacing

OGDEN AVENUE

EQUIPMENT	TEST DATE	AVERAGE DEFLECTION, MILS 15' SPACING (JOINTS A,B,C)	25' SPACING (JOINTS A,B,C)	40' SPACING (JOINTS A,B,C)
*ROAD RATER	7/25/84	4.87	5.13	5.33
*ROAD RATER	6/4/85	4.52	4.81	5.16
**FWD	9/9/86	6.76	6.97	7.29
**FWD	5/7/87	6.32	6.56	5.95

EQUIPMENT	TEST DATE	AVERAGE LOAD TRANSFER EFFICIENCY, % 15' SPACING (JOINTS A,B,C)	25' SPACING (JOINTS A,B,C)	40' SPACING (JOINTS A,B,C)	CONTROL
*ROAD RATER	7/25/84	75.8	79.9	80.8	77.2
*ROAD RATER	6/4/85	80.1	82.8	81.0	81.6
**FWD	9/9/86	77.0	73.0	69.3	73.3
**FWD	5/7/87	69.6	71.0	71.7	72.2

*ROAD RATER TESTED USING AN 8,000-POUND PEAK-TO-PEAK LOAD APPLIED AT 15 Hz.

**FWD DATA NORMALIZED TO A 9,000-POUND LOAD

TABLE 5

Core Strength Data

CORE	LOCATION	SPLIT TENSILE STRENGTH, PSI
C-8 TOP	CENTER OF "SLAB"	500.5
C-8 MIDDLE	CENTER OF "SLAB"	394.8
C-8 BOTTOM	CENTER OF "SLAB"	127.3
C-15B TOP	CENTER OF "SLAB"	487.5
C-15B MIDDLE	CENTER OF "SLAB"	404.2
C-15B BOTTOM	CENTER OF "SLAB"	324.3
C-17B TOP	CENTER OF "SLAB"	278.1
C-17B MIDDLE	CENTER OF "SLAB"	497.8
C-17B BOTTOM	CENTER OF "SLAB"	367.4
C-22 MIDDLE	CENTER OF "SLAB"	399.5
C-2	CENTER	219.4*
C-11	DESIGN C, 40 FT. SPACING	219.4*

*CONVERTED FROM COMPRESSIVE STRENGTH DATA USING THE FORMULA:
SPLIT TENSILE, PSI = 0.1 (COMPRESSIVE STRENGTH, PSI)

TABLE 6

Cost of Crack Control, \$/Yd.^{2}

DESIGN	JOINT SPACING, FT.				
	15	25	40	60	80
A	0.55	0.33	0.21	----	----
B	3.73	2.24	1.40	----	----
C	1.54	0.92	0.58	----	----
D	----	----	0.45	----	----
E	----	----	0.45	----	----
F	----	----	0.45	0.30	0.23

TABLE 7

Increased Cost (% of Pavement Costs)

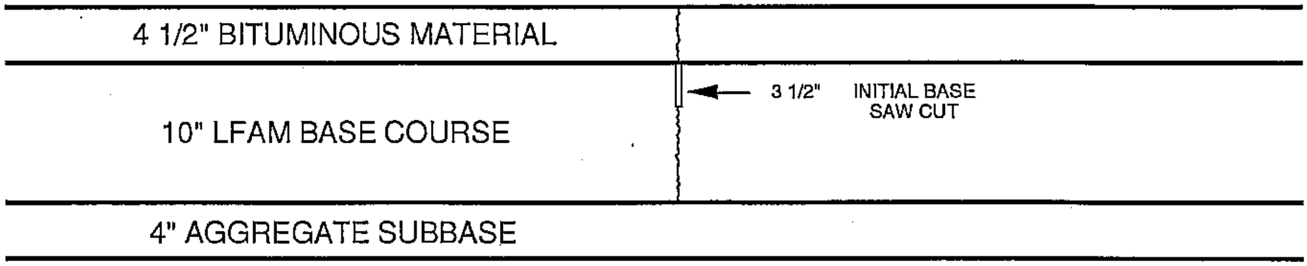
DESIGN	JOINT SPACING, FT.				
	15	25	40	60	80
A	4.1	2.5	1.6	----	----
B	27.9	16.8	10.5	----	----
C	11.5	6.9	4.3	----	----
D	----	----	3.3	----	----
E	----	----	3.3	----	----
F	----	----	3.3	2.2	1.7

TABLE 8

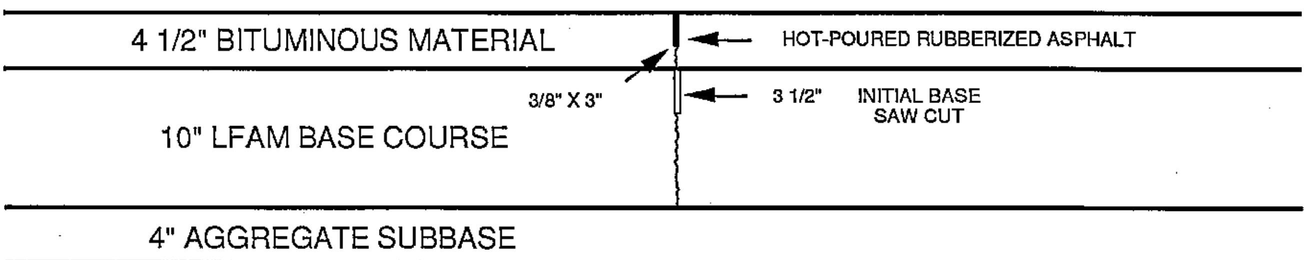
Increased Cost (% of Total Project Costs)

DESIGN	JOINT SPACING, FT.				
	15	25	40	60	80
A	1.4	0.9	0.6	----	----
B	9.7	5.8	3.6	----	----
C	4.0	2.4	1.5	----	----
D	----	----	0.9	----	----
E	----	----	0.9	----	----
F	----	----	0.9	0.6	0.5

JOINT DESIGN A



JOINT DESIGN B



JOINT DESIGN C

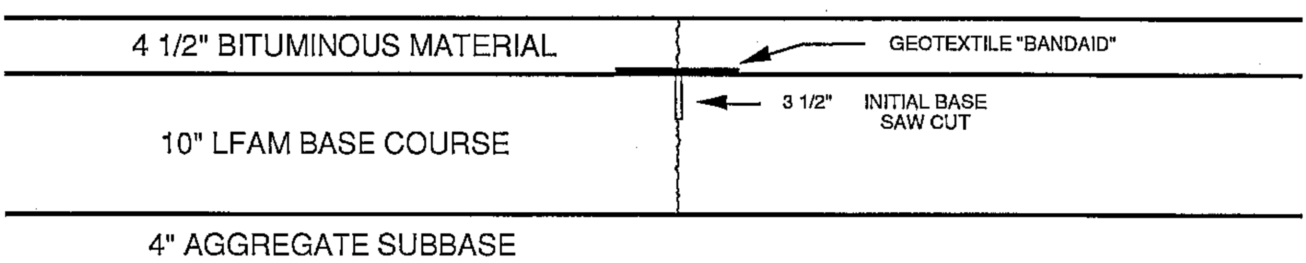


FIGURE 1 : JOINT DESIGNS FOR OGDEN AVENUE

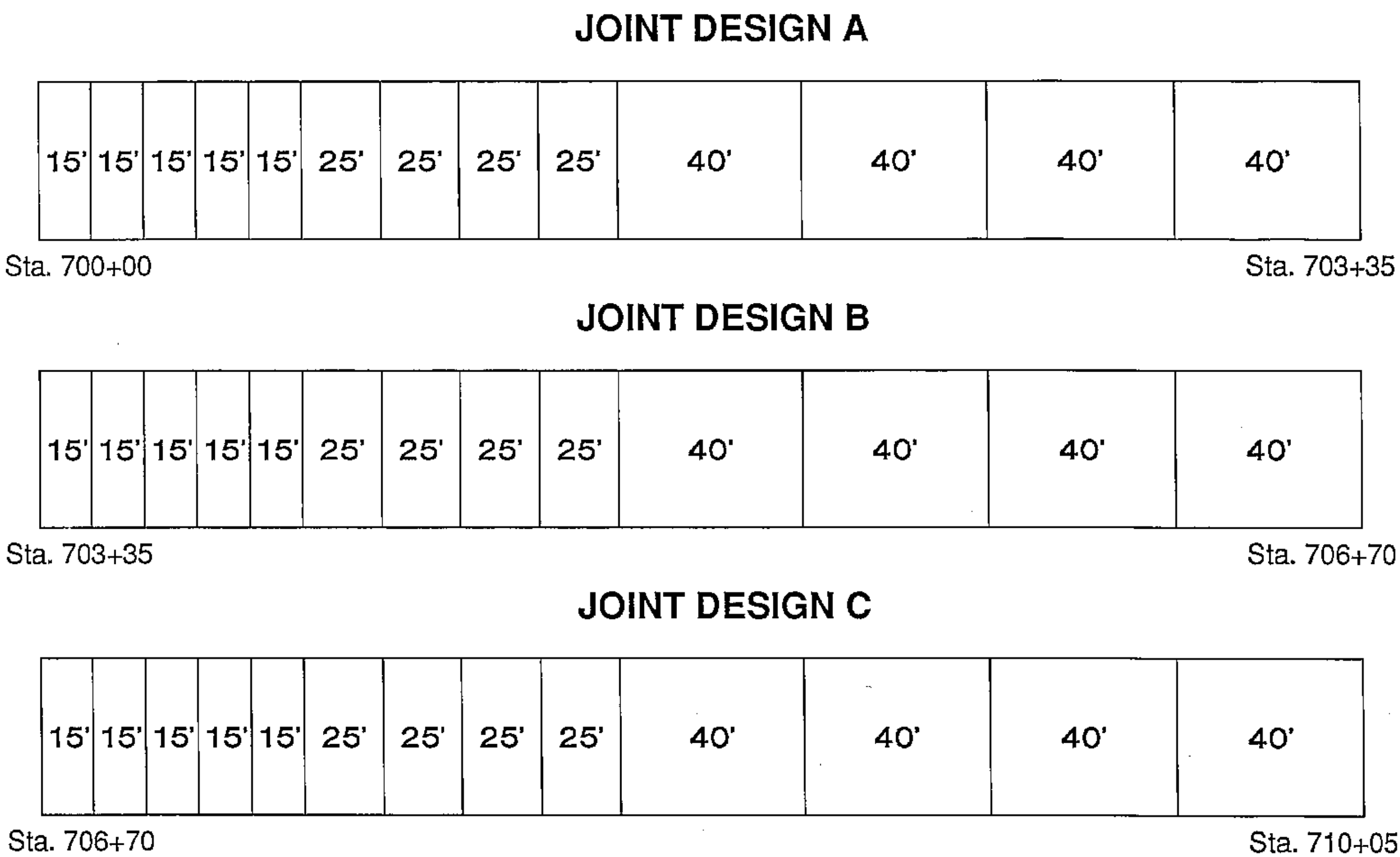
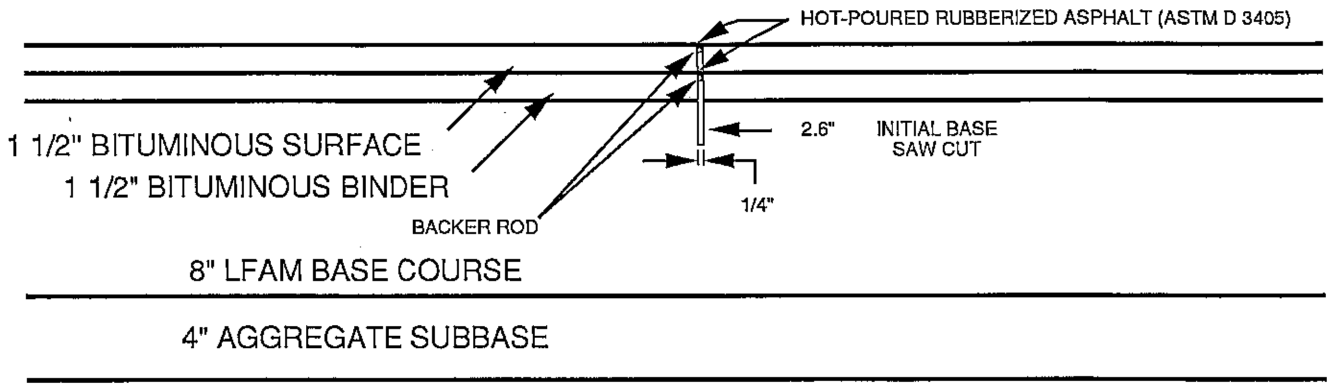
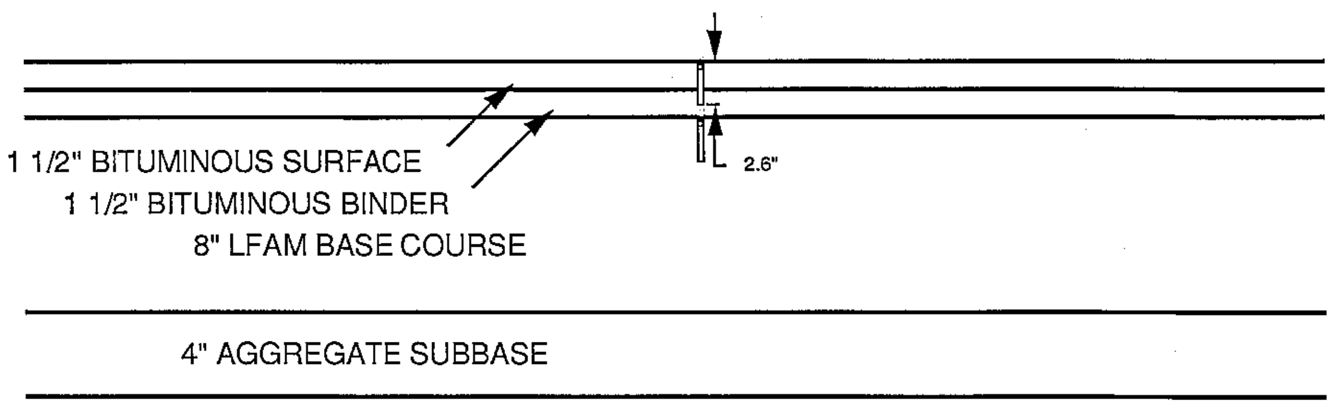


Figure 2: Experimental Joint Layout For Ogden Avenue

JOINT DESIGN D



JOINT DESIGN E



JOINT DESIGN F

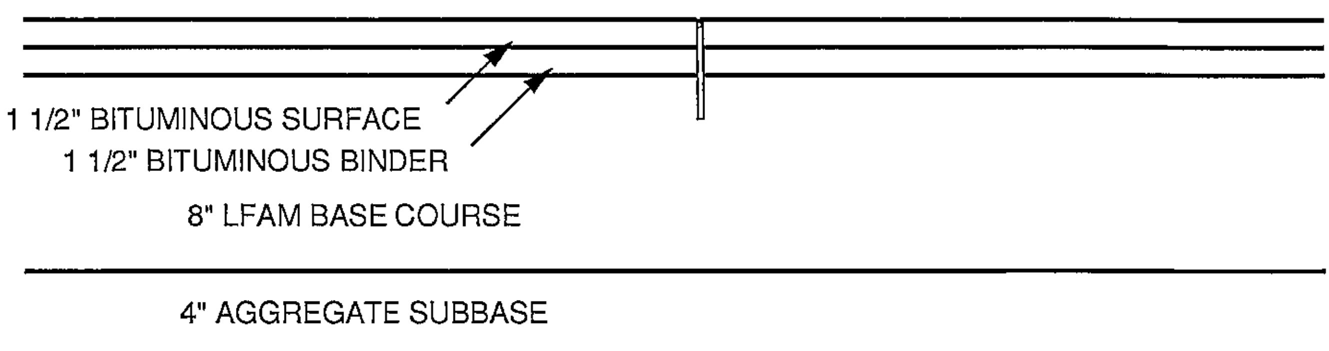


FIGURE 3 : JOINT DESIGNS FOR VOLLMER ROAD

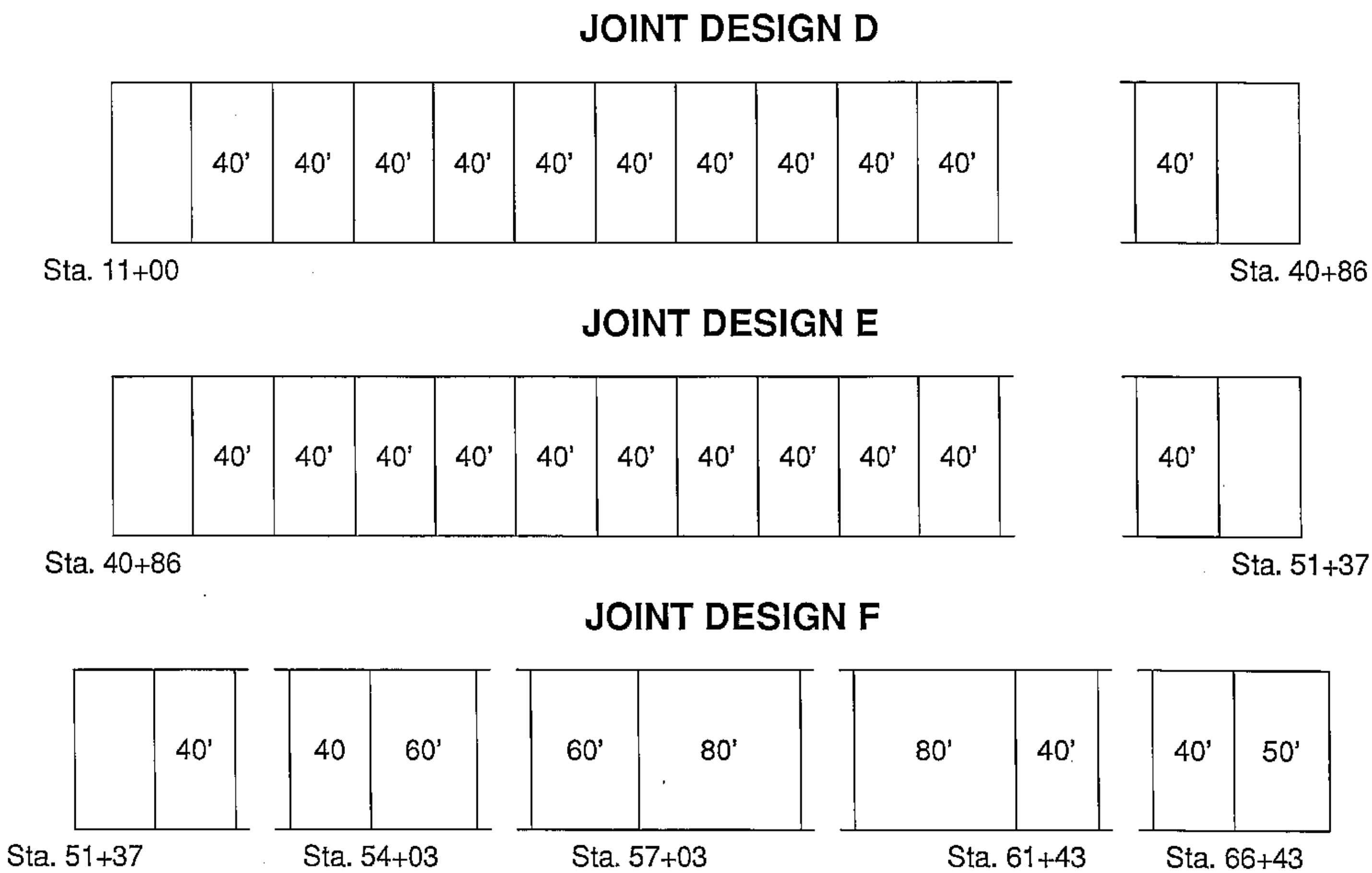


Figure 4: Experimental Joint Layout For Vollmer Road

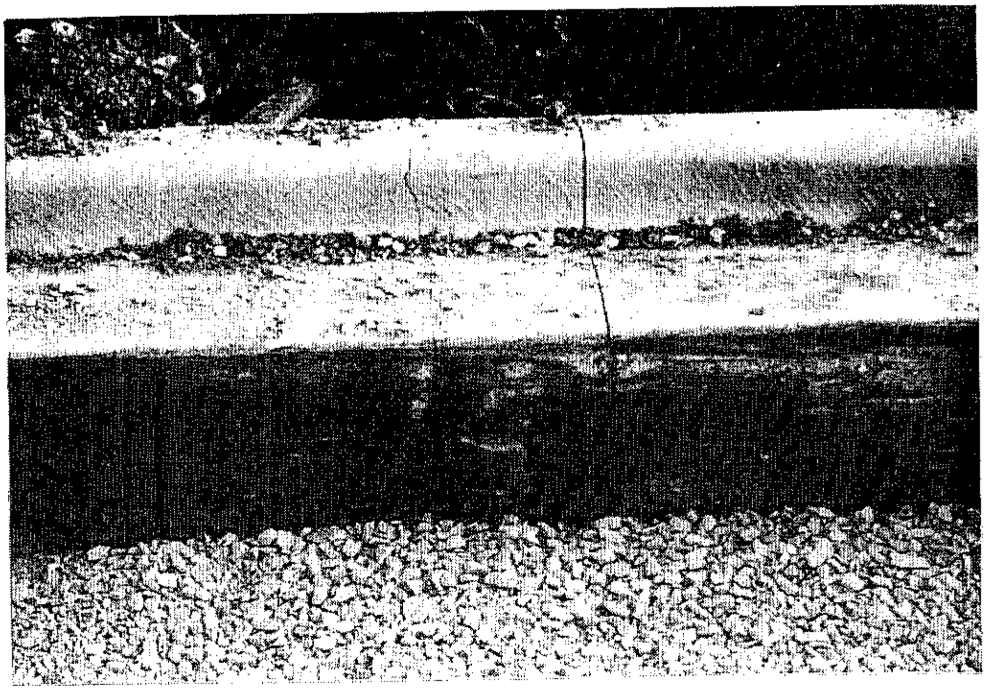


Figure 5: Shrinkage crack next to joint in curb.

Figure 6: Sawing joint in primed LFAM base course.

Figure 7: Cleaning joint in LFAM base course.

Figure 8: Placing geotextile fabric over joints in LFAM base course.

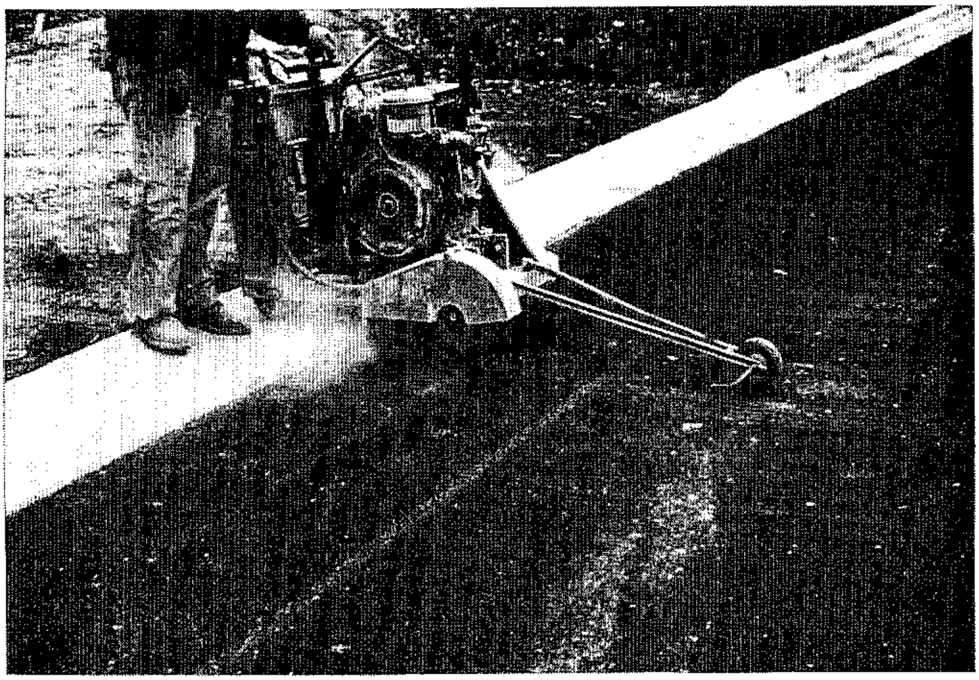


Figure 9: Sawing joint in the asphalt surface for Design B.

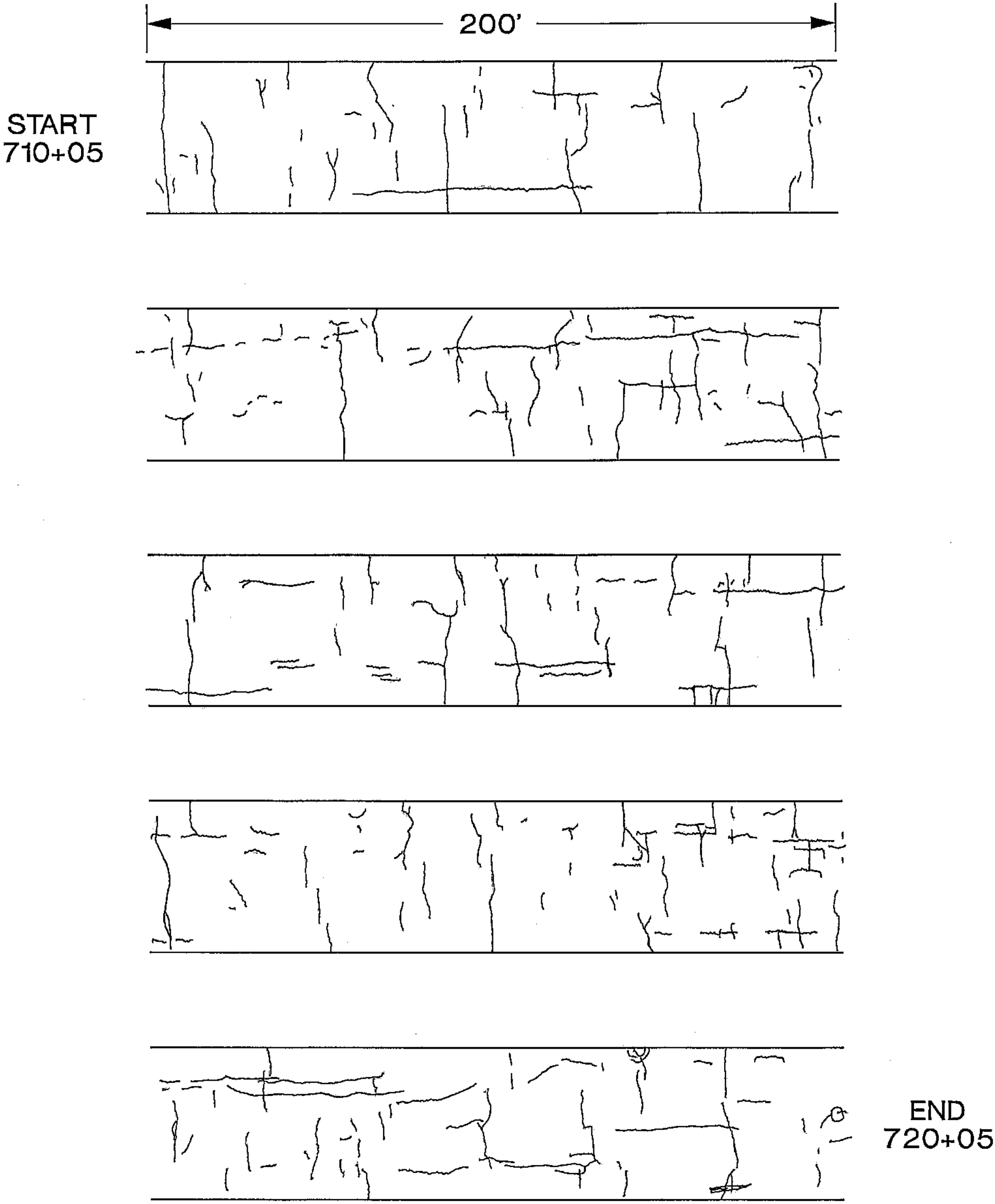


FIGURE 10: Crack Pattern in Control Section on Ogden Avenue

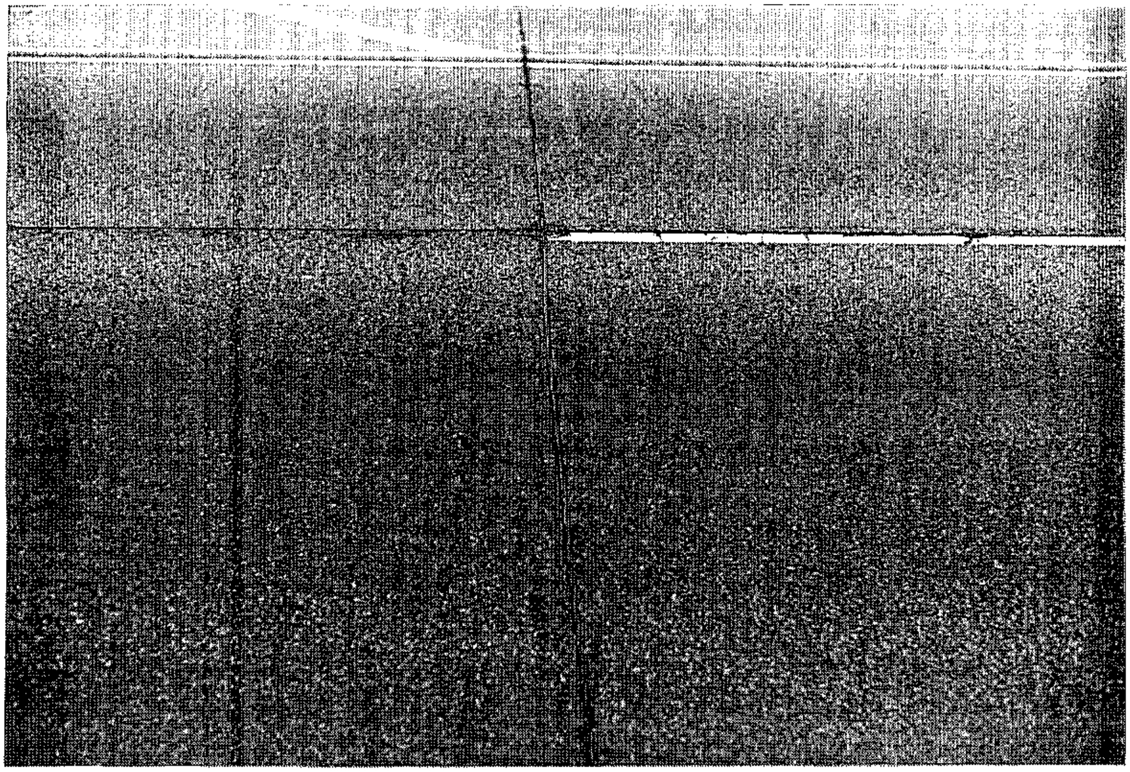


Figure 11: Sealant pulling away from walls of Design B joint with 40-foot spacing.

Figure 12: Cores taken at naturally occurring cracks in control section on Ogden Avenue.

Figure 13: Cores taken between joints and cracks on Ogden Avenue.

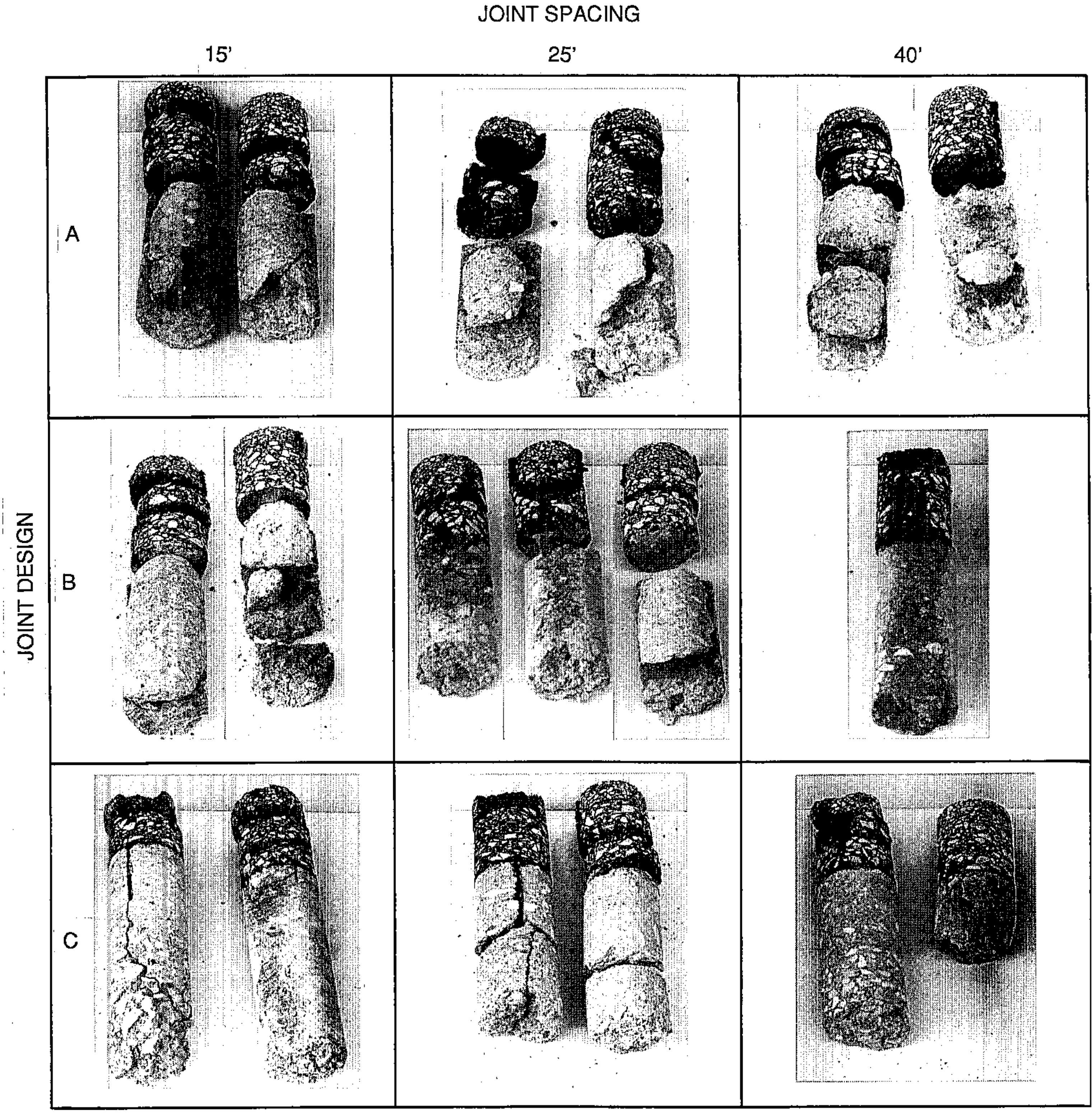


Figure 14: Matrix of cores recovered from Ogden Avenue.

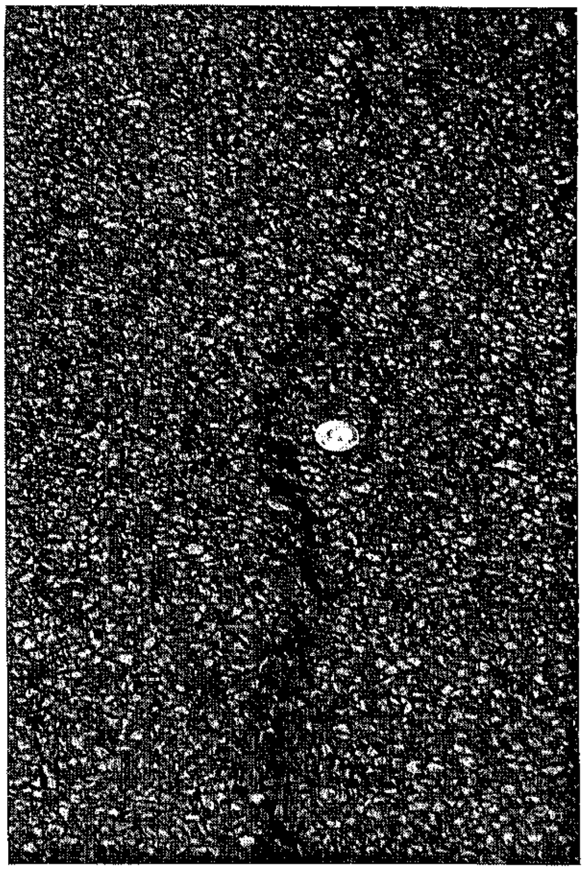


Figure 15: Joint Design A with 25' spacing

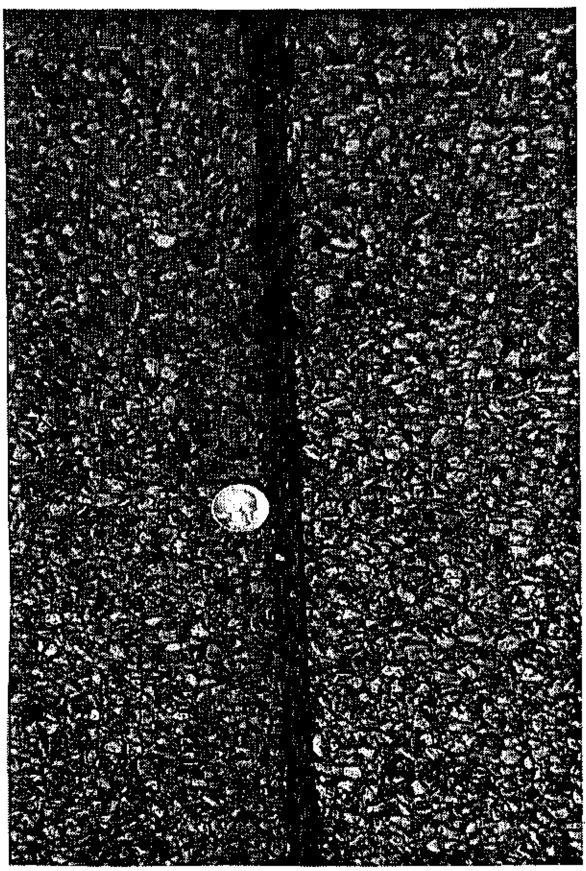


Figure 16: Joint Design B with 25' spacing